Flexibilities of the e-ring lattice

Dong Wang, MIT-Bates

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1, Basic features of current lattice

2, Flexibilities

      Emittance control

      SR level vs. polarization time

      Spin rotation, utility sections

      IR (flat beam, 3-beam, etc.)

      Dynamic aperture

Main features of e-ring lattice

- Energy: 5-10 GeV
- IR: likely round beam, 3-ring
- Polarization: 5-10 GeV, longitudinal,

                    e- injected, e+ self-polarized

- Emittance: very wide range, factor of 10+
- SR: control the SR level
- Geometry: 1/3 RHIC, hori. scheme.

Circumference: 1/3 of RHIC's

- **Syn radiation level**

    we try to make it not a R&D issue

    P_linear ~ 1/sqt(bend radius)

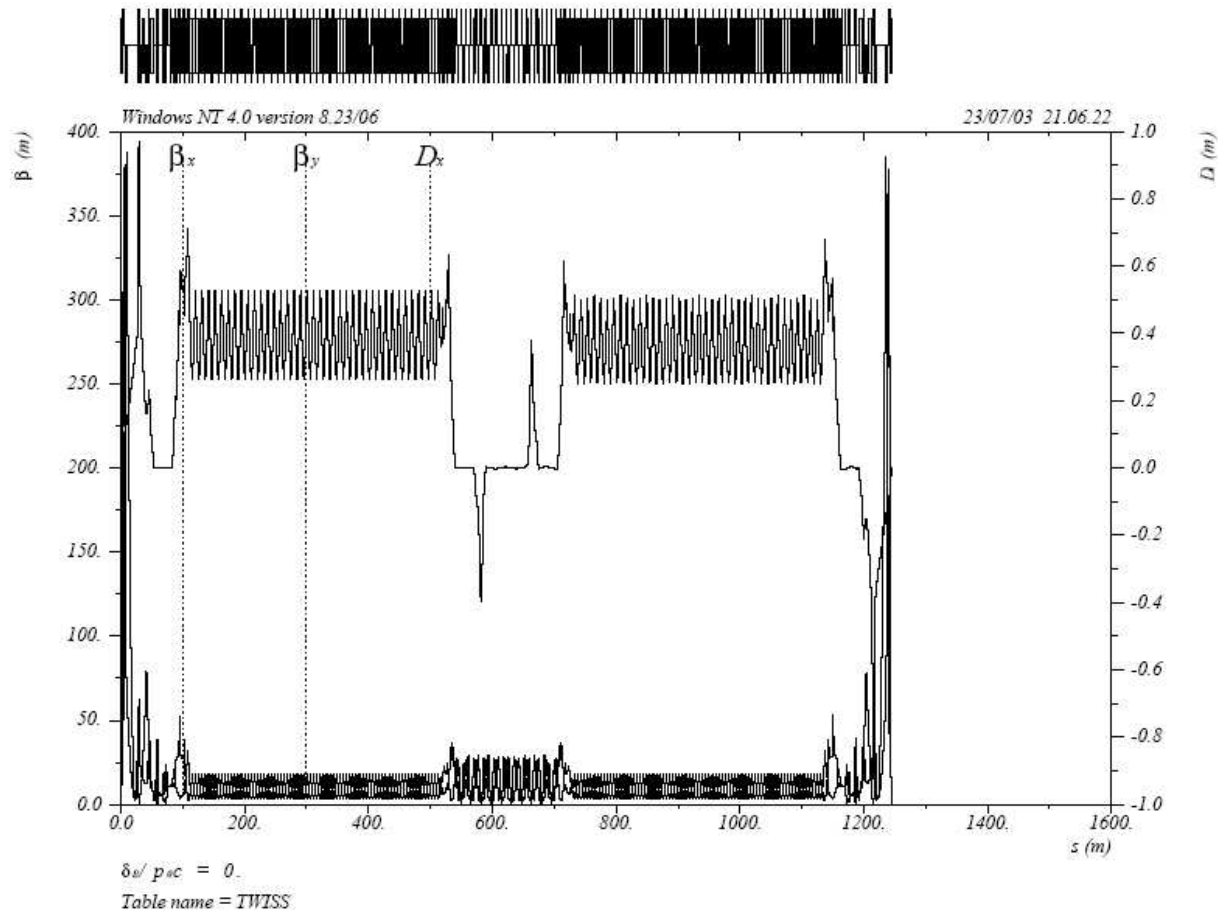- **Emittance control**

    <u>low-end emittance</u> (10 GeV case) is asking more space to accommodate many cell structures (whatever it is, FODO or others)

    high-end emittance is relatively easy in both Linear optics and dynamic aperture

Parameters of current e-ring lattice

	ZDR1.0-10GeV	2003	ZDR1.0-5GeV	2003	e-RHIC 02(sup. B)	SLAC HER	KEKB HER
Circumference(m)	1277.91		1277.91		958.65	2200.00	3016.26
Energy (GeV)	10		5		10	9	8
Bending radius(m)	81.0162		81.0162		58	165	88.95
Bunch Spacing (ns)	35.52		35.52		35.71	16.8/8.4/4.2	1.97
Bunch spacing(m)	10.65		10.65		10.71	1.26	0.59
Number of bunches	120.00		120.00		90.00	415/831/1658	5000
Bunch population	1.00E+11		1.00E+11		1.00E+11		1.40E+10
Beam current(A)	0.45		0.45		0.45	3.00	1.1
Arc Cell	FODO		FODO		FODO	FODO	2.5π Cell noninterlea
Harmonic Number	2028		2028		1169	3492	5120
RF frequency MHz	475.8		475.8		365.7	476	508.9
Energy loss/turn (MeV)	11.44		0.72		15.26	3.52	3.5
					(+supper B) 21.26		
Accelarting voltage(MV)	30		10		30	14	20
Synchrotron tune	0.04		0.034			0.0449	0.011
Total rad. Power(MW)	5.13		0.32		9.57(with S.B)	10.56	3.85
Syn. Rad. Power/m (KW) in Arc	9.63		0.60		18.78	10.19	6.89
from normal bend							
Self-pola. Time at 10GeV(minutes)	22.03		704.85		8.47		
Emittance-x, no coupling (n m.rad)	30.7		93.8		65	49	25
Beta function at IP (cm) y/x	10./10		10./10		10./10	1.5/50	1./33
Round Beam size at IP(um)	38.73		67.08		57.01		
Momentum compaction α	1.79E-03		9.12E-03				2.00E-04
Momentum spread	9.53E-04		4.76E-04		1.60E-03	6.00E-04	6.70E-04
Bunch length (cm)	1.72		3.2		2	1.1	0.4
S.R. damping time(x) (mS)	7.4		58.6		4.2	37.7	23
Beta tune Ux	30.579		17.808		27.48	24.62	44.51
Beta tune Uy	28.649		15.722		21.9	23.64	42.29
Natural chromaticity x,y	30nm: x=-61.80, y=-56.38		90nm: x=-44.86, y=-35.89		x=-76, y=-53		

e-ring lattice at 10GeV

Emittance control

Emittance(h)= 36 nmrad and larger, at 10 GeV.
        90 nmrad at 5GeV, (360 nmrad at 10GeV).
Conventional FODO can do the job with **1/3 RHIC circ**.

Arc lattice: 76 FODO cells + dispersion suppressors.
Phase advance: 90 degrees for 36 nm at 10GeV
                        lower emit possible, depend on DA
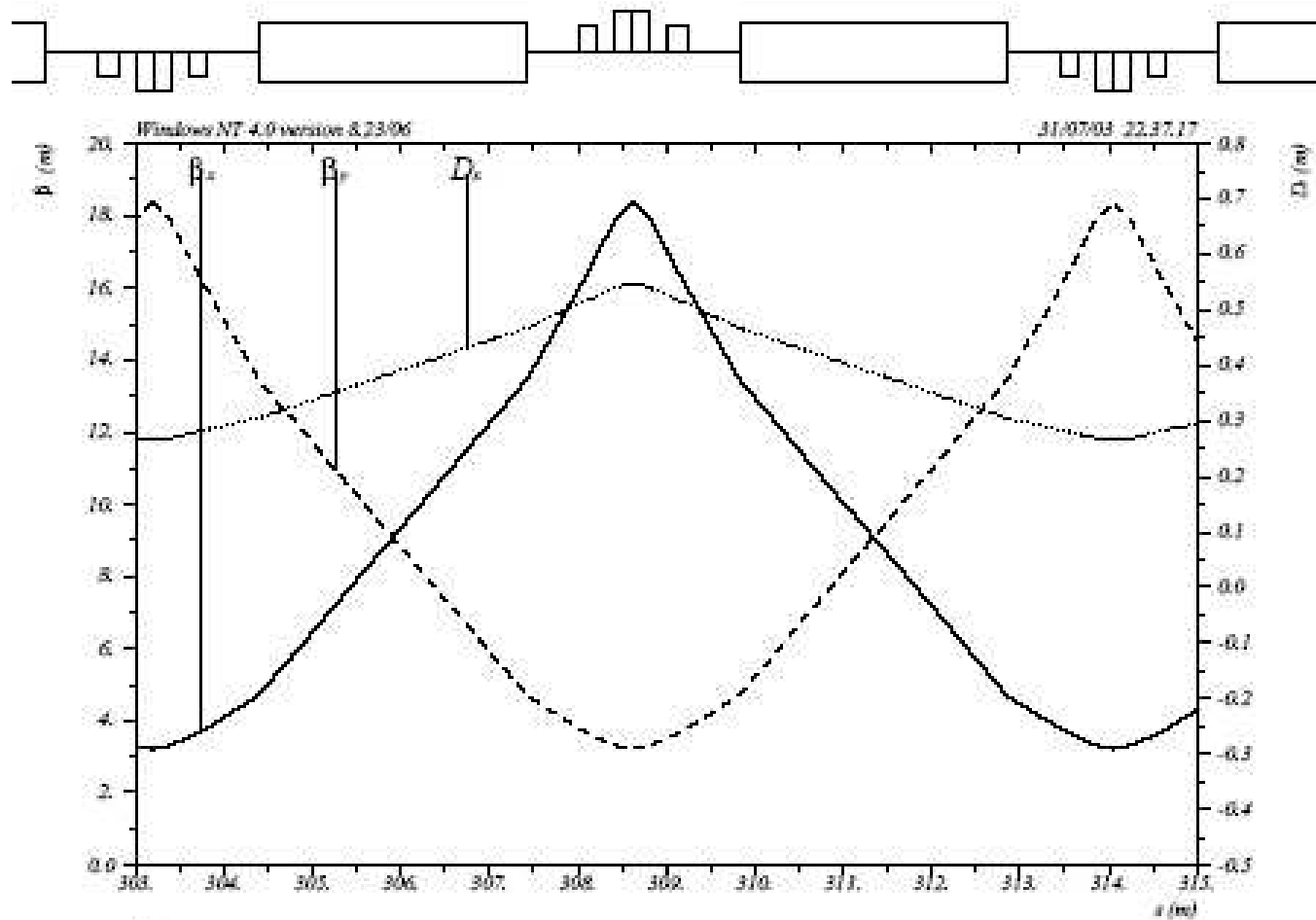   ~10 degrees for 360(90) nm at 10(5) GeV

Distance between quad&sextupole: 0.2 m
Distance between quad-dipole: 0.6 m, still some space
Space for possible emittance wigglers.

Arc: FODO lattice
flexible in emit, low sextupole strength

Flexibilities in emittance
(from real e-ring lattice calculations with MAD)

Emittance vs. phase advance of the FODO cell

Beam emittance(nm.rad)

Phase advance of new FODO cells(degree)
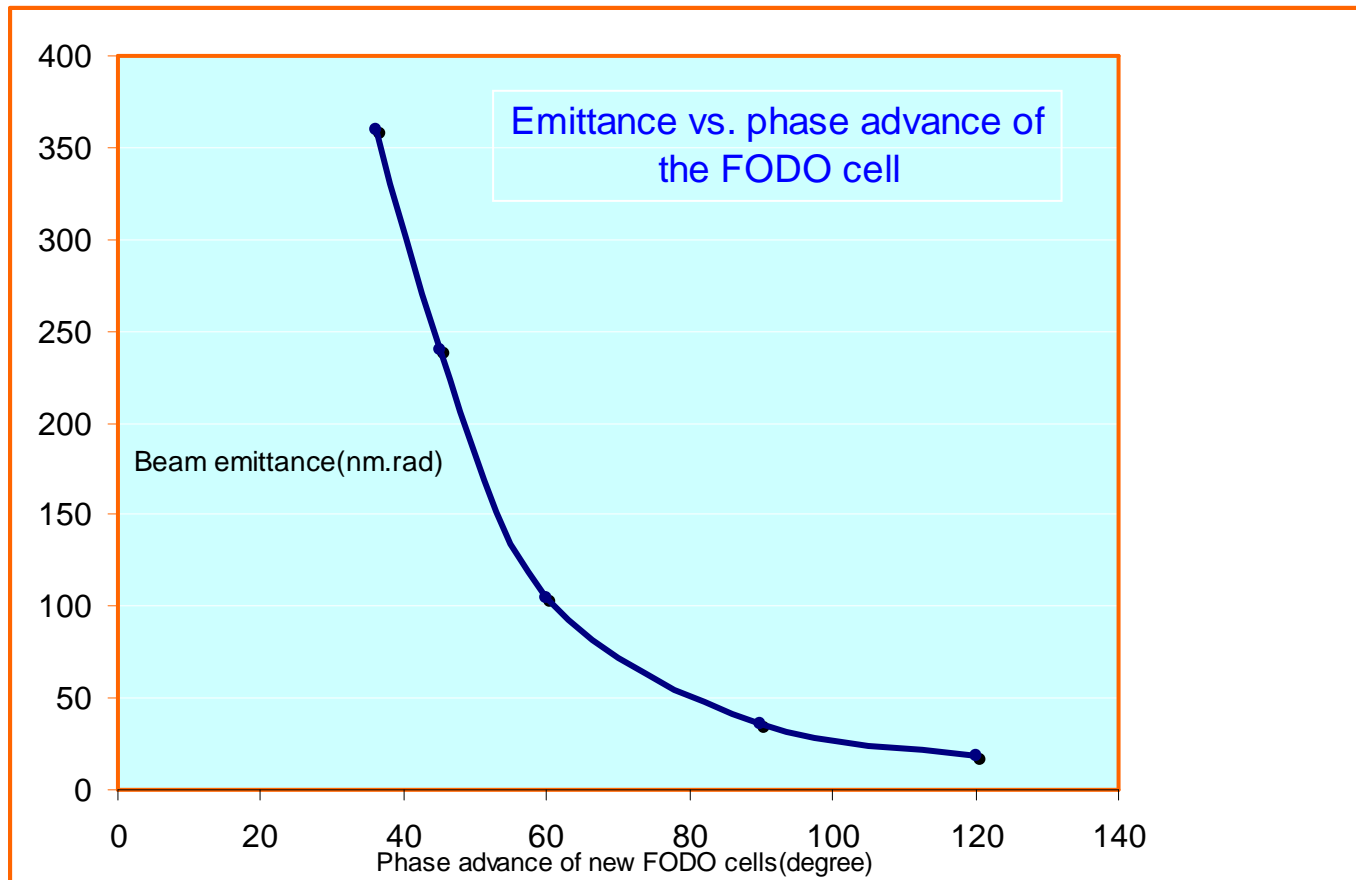
SR issue, pol. time& circumference

For fixed beam energy, current, circumference,

P_sr_linear(kw/m) x Polar. Time = const

Bending radius in new design: ~ 81m,

SR power density= **9.6 kW/m**, <SLAC B-F level !

So this is no longer an R&D issue.

Polarzation time: **22 minutes**

 (in ¼ RHIC cir. design, radius need to be ~57m, in this
   sense, 1/3 RHIC circumference is a must.)

Flexibility in dipole length: 3.03m to ~3.8m (tight design)

Maximum bending radius can be >100m,

then **~5 kW/m and ~40 minutes**, respectively.

Spin rotators: anti-symmetric

Workable from 5-10 GeV, coupling compensation included

Bending angle in each side of rotator: 92.29 mrad,
      (ending angle distribution: depends on IR designs)
      1st dipole: 10.29 mrad, 2nd dipole: 15 mrad,
      (reduced significantly from original but still <u>too large</u>)
      3rd&4th dipole: 33.5+33.5 mrad

Polarization and spin matching
      sending lattice to DESY. crosscheck at MIT&BNL.
      alternative for utility section is done: no dipole.

Utility sections for inj, RF, etc.
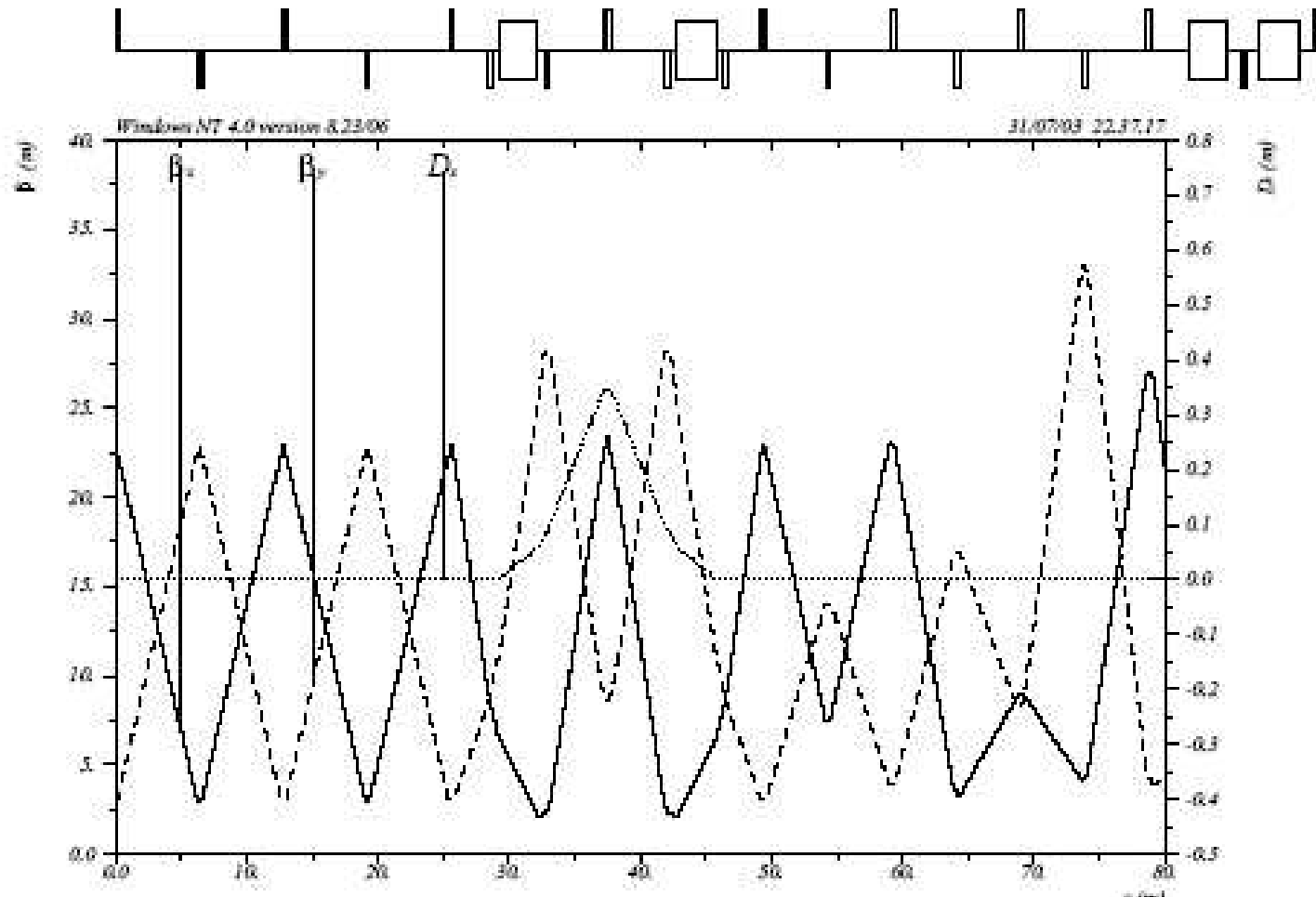
Non-dipole utility section is also done

Interaction Region: changing fast

- IR designs are changing fast in recent 2 weeks, see talks of <u>Abhay, Bernd, Brett, Chris, Vadim,</u> etc.

- Hard to separate yellow and blue rings, may have to accommodate 3 rings?

- Current IR:

  very preliminary. less consideration on SR, maybe too conservative on quads

Lepton IR optics: round beam

Beta* : 0.1/0.1 m

- 1st quad, ~1.3m from IP, max gradient, ~13 T/m,
- combined funciton, (BNL made such one for HERA).
- 2nd quad, finish at ~4.5m(1st quad for hadron at ~5m)

- 3rd quad, ~8m from IP.

   Beta_max: ~380/380, too large, but DA is still acceptable

 Brett Parker's new design: 1st Q is 0.8m to IP and stronger
, beta_max is ~80 m, much better!! (if detector allows)

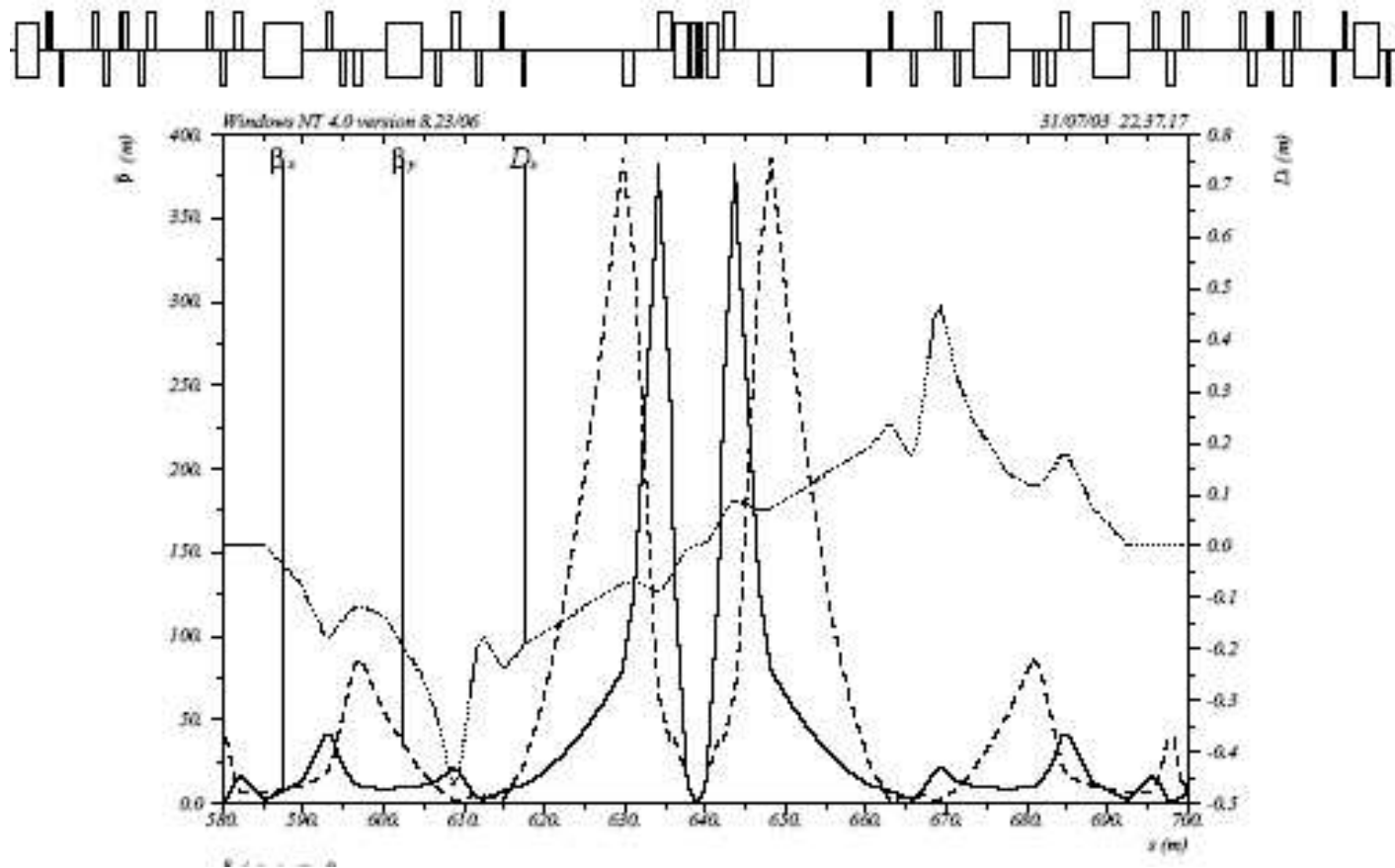## Beam separation (hori. scheme, BINP)

   PEP-II type, 0.6m long dipole next to IP + following Qs,
               Abandoned, permanent magnet is not flexible
   HERA-type, move first Q to 0.9 m or so from IP,
               SR fan problems seen by Montag. Aperture..

e-RING IR optics (including rotator)

Flat beam: why consider it?

·about this scheme, **everything is proved** in HERA operation (luminosity and polarization)

• less concerns for e- beam polarization

• natural for e beam

• less constraints on optics: tunes, special insertions, etc.

Known disadvantage:

• unequal beam-beam parameters. may reduce luminosity performance a little bit. The question is how much?

• need shorter bunch (proton, e beam has no problem)

Typical parameters of elliptical(flat) beam scheme for eRHIC

A lot of choices for elliptical beam parameters.

Here we propose some typical parameters for discussions.
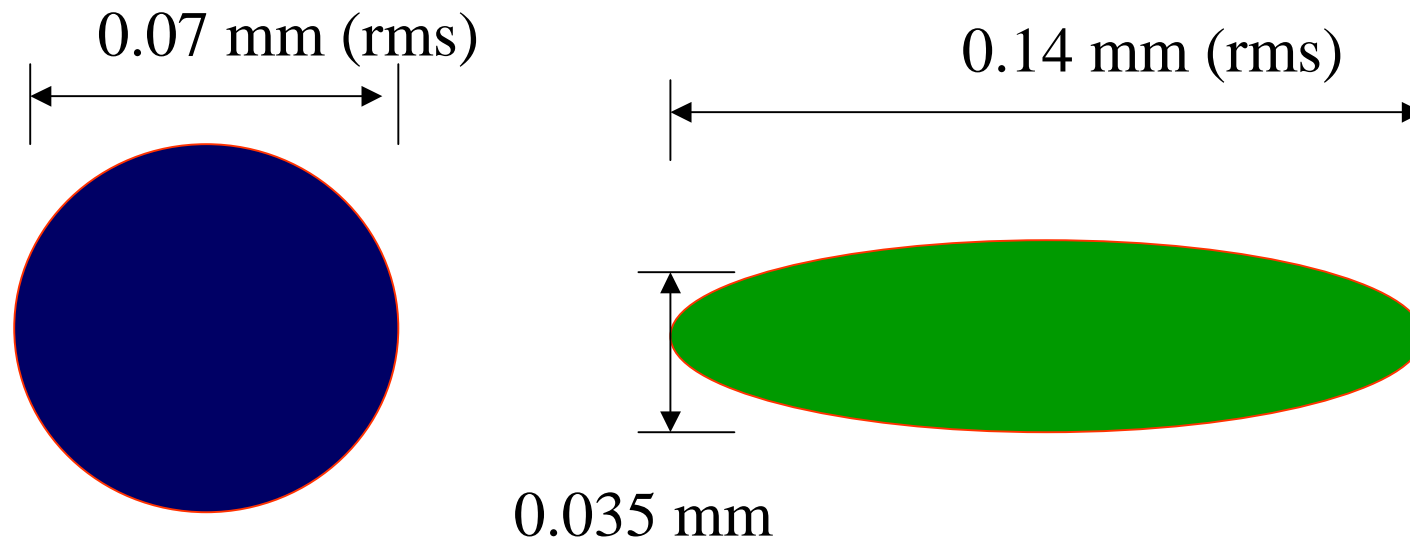
Assuming both beams are matched, i.e.,

Luminosity and beam-beam formulae can be written as

$$L = \frac{N_p I_e}{4\pi e \varepsilon_x^p \sqrt{\beta_x^p \beta_y^p}}$$

$$\Delta \nu_{x,y}^e = \frac{r_e N_p \sqrt{\beta_{x,y}^p}}{2\pi \gamma_e \varepsilon_{x,y}^e (\sqrt{\beta_x^p} + \sqrt{\beta_y^p})}$$

(HERA convention)

Beam sizes in IP, elliptical beam in eRHIC

A typical case: eRHIC e-p collision(10GeV vs. 250GeV)
Example: a h/v beam size ratio at IP of 4:1(HERA: ~3.7:1)
Not so 'flat'. In e+e- colliders, it is 10:1 to 100:1.

0.07 mm (rms)   0.14 mm (rms)

0.035 mm

round beam   **eRHIC**   **elliptical beam(4:1)**
Beta*=0.5m   *proton*   beta*=2.0/0.125m
Beta*=0.1m   *elecrton* beta*=0.17/0.06m

Parameters for a flat beam scheme
To reach same luminosity as round beam
(10 GeV e- vs. 250GeV p beams as an example for discussions)

	eRHIC (flat)	HERA (flat)	eRHIC (round)
Proton:			
Beta_x at IP	2.0 m	2.45 m	0.5 m(0.3m?)
Beta_y at IP	0.125 m	0.18 m	0.5 m
Emittance(geo.)	9 nm	5.1 nm	9 nm
Tune shift	0.0055/0.0038	0.003/0.001	0.005/0.005
Electron:			
Beta_x at IP	0.17 m	0.63 m	0.1 m
Beta_y at IP	0.06 m	0.26 m	0.1 m
Hori./ver. Emittance	100/18 nm	20/3.4 nm	43/43 nm
Tune shift	0.041/0.061	0.034/0.052	0.05/0.05

Proton bunch population is assumed to be 2E11.   I_e-=450mA
For same luminosity: tune shifts exceed limits 0.05(e)/0.005(p) a little bit.

Assume same beam-beam limit apply
Luminosity is about 70% of that of round beam
with *lowered e and p(ion) bunch current*.

principle is same for 0.25m beta* etc.

In act still a lot of room for parameter choice

Basically,
- lower electron beam horizontal emittance, e.g., ~50 nm.
- less flat beam, e.g., 3:1 ratio in beam dimensions
- larger beta_y* for proton beam, e.g., 0.15~0.2m, then longer bunch length permitted.
- better ratio of h/v beam-beam parameters, good for lum.
- larger beta_x* and beta_y* for e- beam, relaxed IR optics

Optics at IR with flat beam

- Easier than round beam (same beam size).
- Doublet can replace triplet (if falt scheme only),

  1, save space for hadron quads

  2, help SR fan problem.

- Need to see hadron optics still.
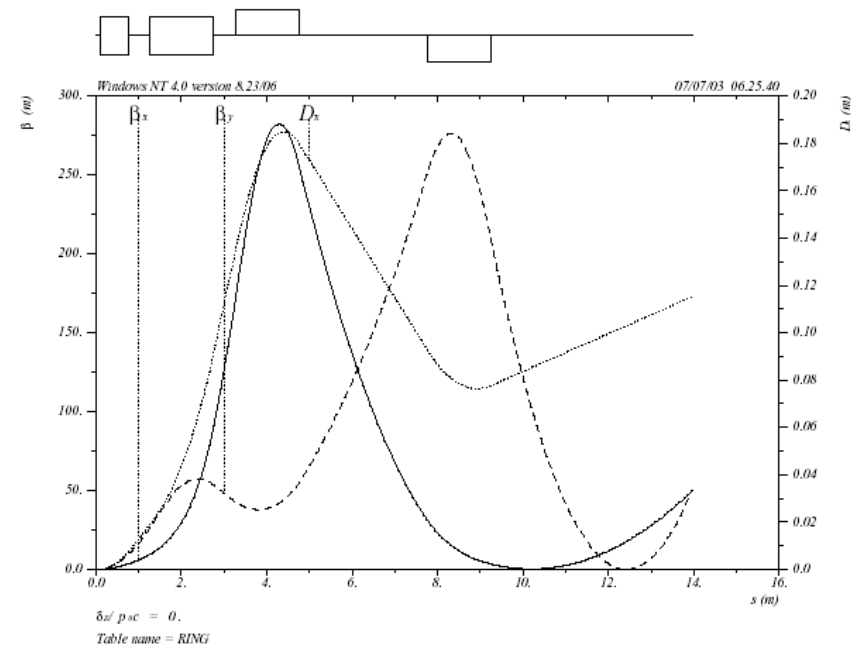
Example of a flat beam IR optics

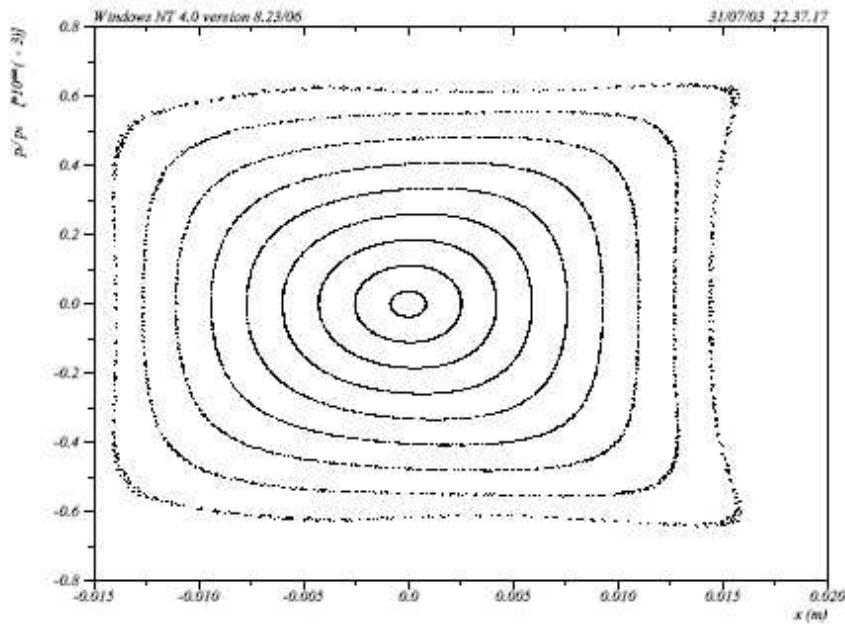# General questions for 3-beam IR

- Can eRHIC operate with both lepton-hadron and hadron-hadron collisions at same time?

  Is total beam-beam tune-shift for hadron beam OK? (0.005 from e-p, how much from p-p or Au-Au at same time?)
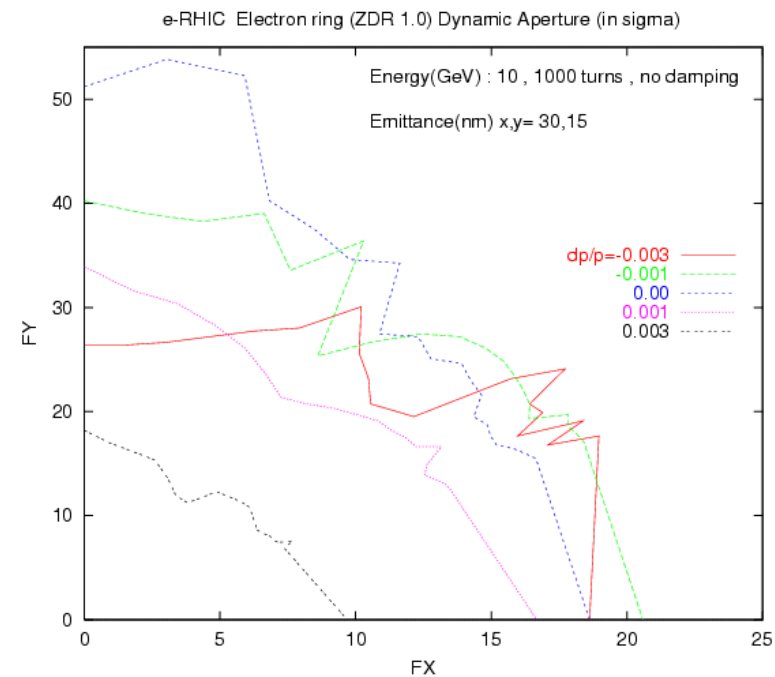
- Can we avoid crossing angle?

  (e beam is fine, w/wt crab cavity)

Dynamic Aperture
Promising so far, 20 sigma for 10 GeV, more for 5GeV lattice(large emit)

Phase space at symmetry point, beta_x=20m,   aperture>15mm.

DA, more results in FW and JC' talks

Summary

Current e-ring optics

- 1/3 RHIC circumference
- Very flexible optics, emittance varies from 30nmrad to 360 nmrad, for round and flat beam operations at 10 GeV and 5 GeV
- Spin rotators embedded
- Promising dynamic aperture
- Enlarged bending radius results in low SR level , *less than SLAC PEP-II level.*
- Flat beam is explored. Seems fine, especially if IR design has difficulties.
- Some open questions in IR configurations. More studies under way by several people.